For More Information

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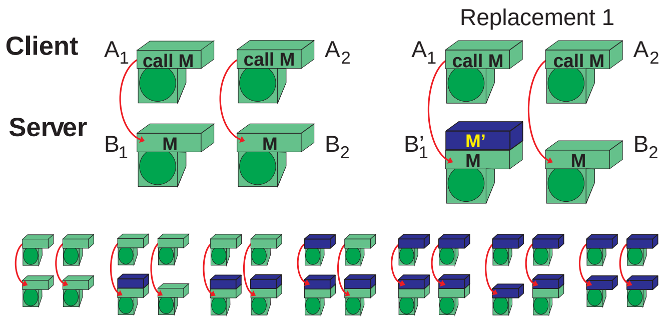
How Far Have We Come?

- **Developing complex application software is hard**
- **Using Totem, Eternal can make it easier by**
  - **Hiding distribution, replication, consistency, and the handling of faults**
  - **Exploiting replication to provide fault tolerance and to allow the system to be evolved dynamically**
  - **Providing location transparency and interoperability using commercial CORBA ORBs**
- **Eternal incurs reasonable overheads for interception, replication and multicasting**
- **Eternal will enable us to build fault-tolerant, evolvable distributed application systems that can run forever**

Evolution of Objects and Interfaces



Evolution of Objects and Interfaces

To add a parameter to an existing method

- Create a new method with the additional parameter
- Replace server replicas, one at a time, with replicas that use both old and new methods
- Replace client replicas, one at a time, with new replicas that invoke the new method
- Replace server replicas, one at a time, with replicas that use only the new method

The Eternal Evolution Manager

- Exploits replication to allow both hardware and software to be removed and replaced, while the system is live
- CORBA’s interoperability permits new hardware to be substantially different from old hardware
- Upgrades to the software objects are performed, one replica at a time, with state transfers from existing replicas to new replicas
- Upgrades to the software objects and interfaces require a sequence of replacements
- The Eternal Evolution Manager is programmed, and executes, as CORBA objects

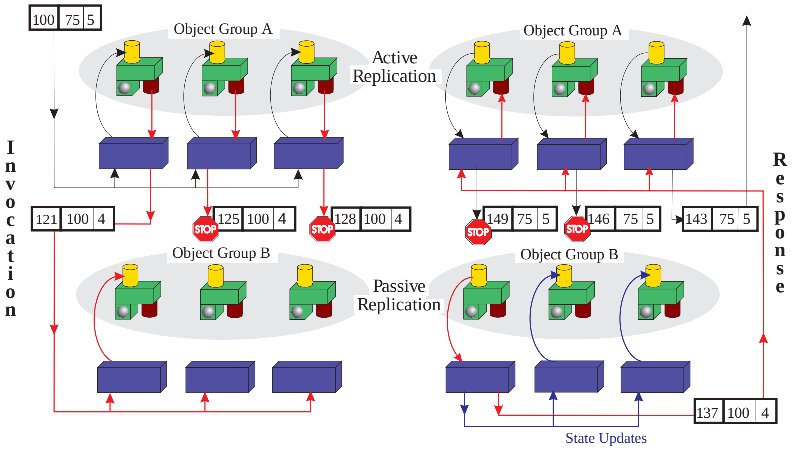
The Eternal Resource Manager

- Distributes replicated objects across the system to meet fault-tolerance and load-balancing objectives
- Specifications in the Interface Repository
  - Quality-of-service requirements, such as real-time response time
  - Resources needed by each object for each operation
  - Capabilities of available processor and network resources
- The Eternal Resource Manager is programmed, and executes, as CORBA objects

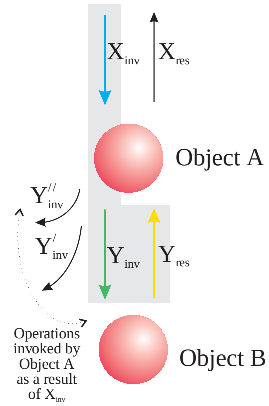
Exception Handling in Eternal

- Application-specific exceptions
  - Exactly the same for all replicas
  - Returned to the client object as the result of its invocation
- Platform-specific exceptions
  - May be different for different platforms
  - Handled locally and not returned to client object
  - May result in the local replica of the server object being terminated
  - May involve a recovery action, including the creation of a new replica by Eternal

Use of Operation Identifiers



Operation Identifiers



Invocation Identifier for Operation Y

Timestamp assigned by Totem to message Y_{inv}	Timestamp assigned by Totem to message X_{inv}	Sequence number assigned by Eternal to operation Y

Unique Operation Identifier

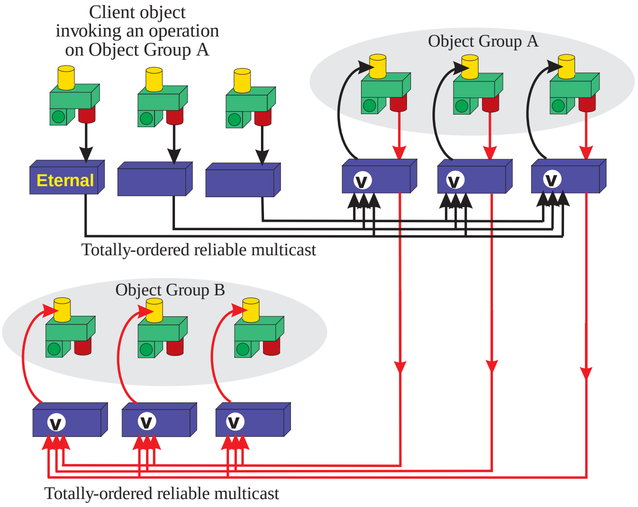
Timestamp assigned by Totem to message Y_{res}	Timestamp assigned by Totem to message X_{inv}	Sequence number assigned by Eternal to operation Y

Response Identifier for Operation Y

Need for Operation Identifiers

- In passive replication, to detect and suppress duplicates when
  - Primary replica invokes an operation and then fails, leading to possible reinvocation after the election of a new primary
- In active replication, to detect and suppress duplicates when
  - Multiple replicas invoke the same operation
  - Multiple replicas respond with the same results
- In majority voting, to ensure that
  - Voting algorithm votes on the same invocations and the same responses

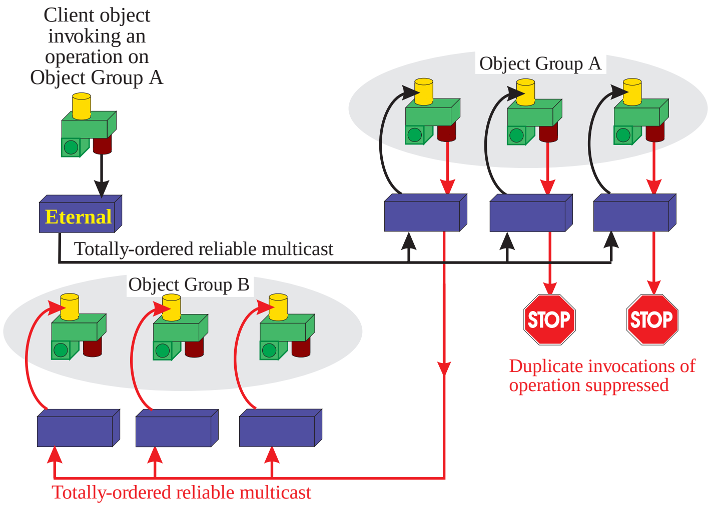
Majority Voting



Majority Voting

- Active replication with majority voting on each invocation and response
- Application is shielded from crash, timing, omission and commission faults
- Needs a more robust group communication protocol that also protects against commission faults
- Computational cost – cost of performing the operation by each replica plus the cost of majority voting by the Eternal Replication Manager
- Communication cost
  - Three or more multicast messages for invocation
  - Three or more multicast messages for response

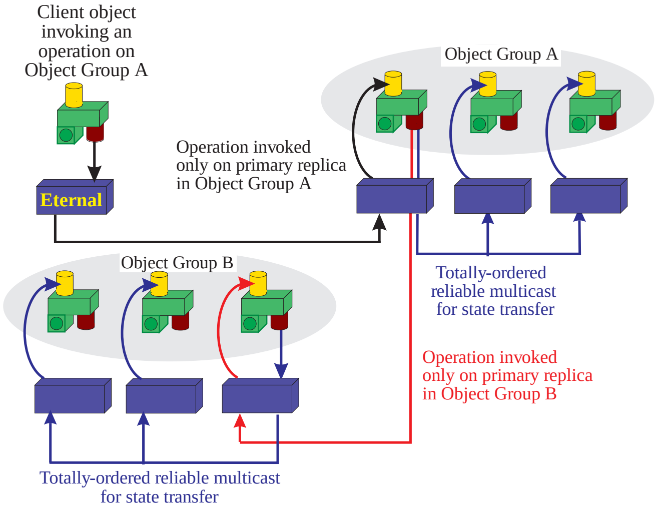
Active Replication



Active Replication

- Each replica of an object performs the same operations in the same order, thereby guaranteeing consistency of the states of the replicas
- Failure of a server replica is transparent to a client object as long as there are two or more server replicas
- Application is shielded from crash, timing and omission faults
- Computational cost – each replica performs the operation
- Communication cost
  - One or more multicast messages for invocation
  - One or more multicast messages for response

Passive Replication



Client object invoking an operation on Object Group A

Operation invoked only on primary replica in Object Group A

Object Group A

Totally-ordered reliable multicast for state transfer

Object Group B

Operation invoked only on primary replica in Object Group B

Totally-ordered reliable multicast for state transfer

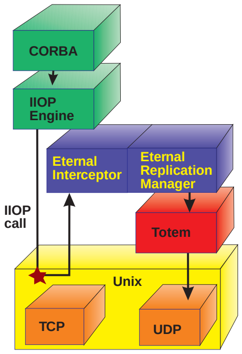
Passive Replication

- Single primary replica performs invoked operation and returns the results of the operation
- Eternal transfers state from the primary replica to the non-primary replicas at the end of the operation, thereby ensuring consistency
- Application is shielded from crash faults and timing faults
- Computational cost – only the primary performs the operation
- Communication cost
  - One multicast message for invocation
  - One multicast message for response
  - One or more multicast messages for state transfer, which may be significant if the state is large

The Eternal Replication Manager

- **Object group abstraction provides replication and group transparency**
- **Operations to be performed on an object are multicast to the object group (consisting of its replicas)**
- **Both client and server objects can be replicated**
- **Passive replication, active replication and majority voting are supported and can coexist**
- **Operation identifiers allow duplicate operations to be detected and suppressed**
- **Nested operations of any depth are supported**

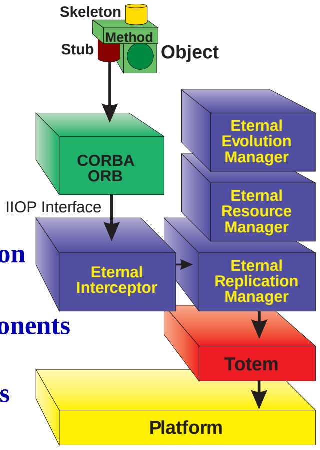
The Eternal Interceptor



- Commercial CORBA ORBs are complex and proprietary, but all provide IIOP over TCP
- But TCP does not provide total ordering of messages within multicast groups
- Intercepts the IIOP calls to TCP using the /proc facility of Unix
- Redirects the calls to Totem via the Eternal Replication Manager
- Works with Iona’s Orbix, Sun’s NEO, Visigenic’s VisiBroker, Expersoft’s CORBAPlus, HP’s ORBPlus, Chorus’ COOL, OOC’s OmniBroker, Xerox’s ILU, Olivetti’s Omni-ORB 2

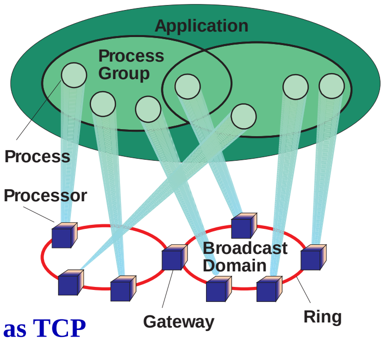
The Eternal System

- Implemented on top of Totem
- Application programmer interface is object-oriented, rather than message-oriented
- The Eternal system provides
  - Object replication and distribution
  - Fault detection and recovery
  - Continued operation in all components of a partitioned network
  - Hardware and software upgrades in a live system
- Uses standard IIOP interface, works with any commercial CORBA ORB



The Totem System

- Provides reliable totally ordered delivery of multicast messages to processes in process groups over single or multiple local-area networks
- Delivers messages in a consistent total order that respects causality despite
  - Message loss
  - Processor and process faults
  - Network partitioning
- Maintains the membership and topology of the network
- Delivers multicast messages as fast as TCP can deliver messages point-to-point



Maintaining Consistency with Multicast Messages

- Operations to be performed on the replicated objects are contained in messages that are multicast to the processors hosting the replicas, using a group communication system such as Totem
- All of the processors receive the multicast messages in the same total order
- The processors perform the same operations on the replicas in the same total order
- The Eternal system maintains consistency of the replicas
- The replicas of an object are presented as a single object to the application programmer

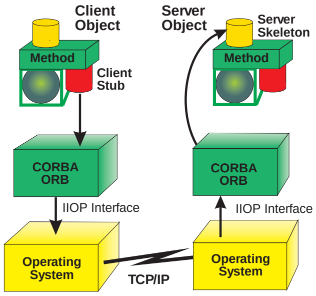
Simplifying the Application Programming

- Our objective is to build systems that are fault-tolerant, adaptive, and evolvable
  - This requires replication of processing and data
  - But, maintaining consistency of replicated data is difficult in the presence of asynchrony and faults
- Application programmers should not be concerned with these difficult system programming issues
- Our objective is to simplify the application programming by
  - Hiding the difficult issues of replication, consistency, fault detection and recovery
  - Separating the functional behavior of the program from the allocation and management of resources

Distributed Object Computing and CORBA

Common Object Request Broker Architecture (CORBA)

- Client requests a server to perform operations for it
- Requests are handled by the Object Request Broker (ORB) to achieve
  - Location transparency
  - Interoperability
- Internet Inter-Orb Protocol (IIOP) provides a clean simple interface for the invocation of operations



Where Are We Going?

- In the past, processing speed and memory capacity have been the limiting factors in computer systems
- In the present, with distributed networked computing, the limitation is network bandwidth
- But processors and networks are becoming faster, and memory is becoming cheaper
- In the future, the limiting factor will be the complexity of the application software

The Eternal System

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